FINE PARTICULATE EMISSIONS FROM STATE-OF-THE-ART SMALL-SCALE AUSTRIAN PELLET FURNACES

CHARACTERISATION, FORMATION AND POSSIBILITIES OF REDUCTION

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Intention of the project (I)

- During the last years fine particulate air pollution (PM$_{10}$) has become a topic of broad public awareness since it is well known that small particulates can cause severe health effects.

- The EU directive 1999/30/EC limits PM$_{10}$ concentrations in the ambient air. In many European regions these PM$_{10}$ limits of 50 µg/m$^3$ (daily mean value) are more often exceeded than the 35 times per year allowed.

- Domestic heating is one main PM$_{10}$ emission source besides traffic and industry.

- Therefore, fine particulate emissions of small-scale biomass combustion plants have to be investigated, evaluated and minimised.
In order to gain more comprehensive information about fine particulate emissions from small-scale biomass combustion plants, a joint project of the

- Austrian Bioenergy Centre, Graz,
- and the
- Institute for Resource Efficient and Sustainable Systems, Graz University of Technology

has been started.

The project is performed in close cooperation with 9 Austrian small-scale biomass furnace and boiler manufacturers.
Definitions – classification of atmospheric aerosols (I)

Source: Wilson and Suh, 1977
PM emissions from biomass combustion plants

Example: Results from test runs at a grate-fired combustion plant (nominal boiler capacity: 440 kWth)
Aerosol formation in small-scale biomass furnaces

Coarse fly ashes

KCl, K₂SO₄, K₂CO₃ etc.

Gas phase reactions (KCl, K₂SO₄, ZnO etc.)

K, Na, S, Cl, Zn, Pb, Cd

CO₂, H₂O, CO, CₓHᵧ

Gas phase burn-out (CO₂, H₂O, CO, CₓHᵧ)

Cooling of the flue gas

KCl, K₂SO₄, K₂CO₃ etc.

Small amounts of coarse fly ashes are emitted

Coarse fly ashes are entrained from the fuel bed, transported with the flue gas and partly precipitated in the furnace and the boiler

Release of primary particles, soot formation

Condensation

Coagulation

Nucleation

Bottom ash
Methodology applied

- Test runs at small-scale pellet furnaces
  - test stand
  - field tests

- Measurement and determination of
  - total fly ash emissions
  - particle size distribution and concentration of aerosols
    - low pressure impactor (BLPI)
    - electrical low pressure impactor (ELPI)
  - flue gas composition
    \( O_2, \ CO, \ TOC, \ NO_x \)
  - operation mode of the furnace
    (furnace temperature, load, flue gas temperature)
Systems tested

- state-of-the-art Austrian pellet combustion technologies
- nominal boiler capacity: 15 to 20 kW
- all furnaces were equipped with
  - automatic ignition systems
  - staged combustion
  - automatic boiler cleaning systems
  - automatic de-ashing systems
- different combustion technologies
  (underfeed stoker, overfed burner, horizontally fed burner)
- equipped with water cooled or insulated combustion chambers
- fully automated process control including $\lambda$-sensors or temperature sensors
Measurements performed

- Furnace 1: test stand measurements at different load conditions
- Furnace 2: test stand measurements at different load conditions
- Furnace 3: field measurements at full and partial load
- Furnace 4: field measurements at full load
- Furnace 5: test stand measurements at different load conditions
- Furnace 6: test stand measurements at different load conditions
Results – total fly ash emissions

Explanations: measurements performed with the total dust measurement equipment; partial load: 50% of the nominal load; all results related to dry flue gas and 13 vol% O₂; mean values and standard deviations of at least 3 measurements.
Results – total fly ash, PM\textsubscript{2} and PM\textsubscript{1} emissions at full load

Explanations: measurements performed with the BLPI; all results related to dry flue gas and 13 vol% O\textsubscript{2}; mean values and standard deviations of at least 5 measurements.
Results – particle size distributions during full load operation

Particle mass size distributions

Particle number size distributions

Explanations: measurements performed with the BLPI (mass) and the ELPI (number); all results related to dry flue gas and 13 vol% O₂; ae.d.: aerodynamic particle diameter; mean values of at least 5 measurements
Results — unstable load conditions: start up

Explanations:
PM data from ELPI measurements;
FT ... furnace temperature;
O₂ related to dry flue gas;
PM₁, CO and TOC related to dry flue gas and 13 vol% O₂;
Results – unstable load conditions: load changes

Explanations:
Results of a 5h measurement period with several load changes;
PM data from ELPI measurements;
O₂ related to dry flue gas;
PM₁, CO and TOC related to dry flue gas and 13 vol% O₂;
Results –
chemical composition of the PM$_1$ fraction – inorganic part

Explanations: mean values and standard deviations of at least 3 analyses per furnace investigated;
partial load: 50% of the nominal load
values normalised to 100% without O and C
Results – structure and chemical composition of fine particulates

Explanations: EDX-scan from area marked in the SEM-image; particle sampling during full load operation with a 3-stage impactor; Si originates from the filter material; picture width: 2 µm
Conclusions (I)

- Average total dust emissions during stable full and partial load operation:
  - $<20 \text{ mg/Nm}^3$ (dry flue gas and 13 vol% $O_2$) respectively
  - $<13.3 \text{ mg/MJ}_{\text{NCV}}$

- The average number concentration of small particulate emissions (particles $<1\mu\text{m}$) is in the range of $10^{13}$ particles/Nm$^3$

- More than 95% of the total dust emissions are PM1

- Compared with literature data available for older pellet furnace technologies (emissions up to 100 mg/Nm$^3$), a considerable reduction of particulate emissions due to improved combustion conditions and therefore a considerable reduction of organic aerosols has been observed.
Conclusions (II)

- No significant differences concerning the particulate emissions with respect to
  - full load and partial load operation
  - different furnace technologies applied
  - test runs at the test stand and field measurements

- During start-up as well as during load changes (change from partial to full load), operation conditions with insufficient gas phase burnout and therefore, with increased particle formation occur.
Conclusions (III)

- At stable operation conditions and sufficient gas phase burnout:
  - aerosols formed mainly consist of K, Na, S, Cl as well as Zn and show only minor concentrations of organic C.
  - concerning these operation conditions, mainly the chemical composition of the fuel influences the mass of aerosols formed.

- Consequently, the combustion of fuels with low concentrations of aerosol forming species (e.g. clean wood pellets) causes considerably lower particulate emissions than the combustion of alkaline, S and Cl rich fuels (e.g.: herbaceous fuels).
Conclusions (IV)

During unstable operation conditions causing insufficient gas phase burnout:

- fine particle emissions significantly increase for short operation periods.
- the concentration of the organic carbon content in the fine particulates significantly increases.

Consequently, advanced process control technologies and appropriate furnace designs should be developed and applied in order to keep operation periods at insufficient gas phase burnout conditions as short as possible.
Recommendations

- Two relevant primary measures for particulate emission reduction in small-scale pellet boilers can therefore be recommended.
  - Utilisation of fuels with low concentrations of inorganic aerosol forming species (e.g. softwood pellets).
  - Application of advanced furnace designs and process control systems.

- The substitution of old wood furnaces by state-of-the-art pellet combustion technologies should be enforced and maybe even subsidised by the state respectively regional governments.

- For a further reduction of particulate emissions below the range of about 15 mg/Nm³ secondary measures (e.g. small-scale ESP systems or scrubbers) are needed which are currently under development but not yet sufficiently tested.
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